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**NPG Report No. 1271**

ADDITIONAL  
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**DEVELOPMENT OF  
THE BALLISTIC SYNCHRO-CAMERA**



**U. S. NAVAL PROVING GROUND  
DAHLGREN, VIRGINIA**

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**U. S. Naval Proving Ground  
Dahlgren, Virginia**

**Development of the Ballistic Synchro-Camera  
by**

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and Services Department**

**NPG REPORT NO. 1271**

**Task Assignment No.  
NPG-B-3d-443-2-54**

**30 April 1954**

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ABSTRACT

The Ballistic Synchro-Camera is under development at the Naval Proving Ground in fulfillment of a need for high-resolution photography of experimental missiles whose behavior in flight prohibits the use of conventional micro-flash equipment. The development program is being conducted in three phases, the first of which has been completed and is the subject of this report.

The principle on which this camera works is that of matching continuously the velocity of the image of the missile with the velocity of a film moving behind a narrow stationary slit which is perpendicular to the direction of film travel. Synchronization of the two velocities eliminates the translational movement of the image with respect to the film. Thus, if no other motion is present, a point on the image remains at the same point on the film during traverse of the slit, resulting in a photographic image of high quality and definition.

A camera of this type is ideally suited to the study of large, rapidly moving objects with results comparable in quality to those obtained under more restricted conditions by other methods. The camera is used in daylight with no restriction of ambient light, can be located at safe distances from missile trajectories, and can thus be used in the study of missiles producing dangerous fragments. It is especially suited to the study of rockets and self-luminous missiles. It has been used in studies of discarding sabot missiles, experimental projectiles, rockets, penetration of targets by rockets and projectiles, and fuze action.

In addition to the production of photographs of high resolution, valuable information on missile velocity, yaw and spin can be deduced from the records.

The Phase A Ballistic Synchro-Camera, which is the subject of this report, is a modified 35mm oscillograph recording camera providing continuous film transport at speeds from 300 to 1,000 inches per second. Interchangeable slits, one inch in length and with widths varying from 0.01 to 0.25 inches, are provided with the camera to meet the range of test conditions encountered in the field.

Three Phase A Ballistic Synchro-Camera systems have been developed and are in regular field use at the Naval Proving Ground. Each system consists of two 35mm cameras, adjustable camera mounts, a timing generator and a control box.

FOREWORD

The authority to undertake development of a Ballistic Synchro-Camera under Task Assignment NPG-Re3b-225-1-52 is contained in reference (a). During FY 1953 work was continued under Task Assignment NPG-Re3d-443-2-53, established by reference (b). Current work is being conducted under Task Assignment NPG-B-3d-443-2-54, established by reference (c). This is the 4th partial report on Ballistic Instrumentation, the 1st partial report on the Development of the Ballistic Synchro-Camera, and the final report on the development of the Phase A Ballistic Synchro-Camera.

This report was reviewed by H. R. Pryor, Head of the Physics and Engineering Division, Ballistic Instrumentation Development and Services Department; C. N. Johnson, Jr., Technical Assistant to the Director of Ballistic Instrumentation Development and Services Department; D. W. Stoner, Director of Ballistics Instrumentation Development and Services Department; R. H. Lyddane, Assistant Director of Research; and N. A. M. Riffolt, Director of Research.

INTRODUCTION

For several years the Naval Proving Ground has recognized the need for photographic instrumentation to supplement existing high speed motion picture and microflash photographic equipment required in ordnance development and test programs. Such an instrument should be simple to adjust in the field, useable under normal daylight conditions without a dark chamber, capable of high resolution, and adaptable to general use in the field. In addition, it should be capable of photographing missiles over a wide range of velocities.

An immediate need for such an instrument arose in the late summer of 1951 in the study of experimental sabots for the Angled-Arrow Projectile. It was desired to obtain pictures of the missile soon after it left the muzzle of the gun. Pictures were especially desired for tests in which the missile or parts of the round were subject to failure. These conditions were likely to result in damage to a microflash darkroom and equipment and in loss of the photographic record. Therefore, a camera utilizing the Ballistic Synchro principle was improvised, using a 35mm recording camera. This improvised camera produced pictures which indicated that the design was feasible and led to a proposal for the development of a Ballistic Synchro-Camera which was submitted to the Bureau of Ordnance in reference (d). The first successful pictures employing this principle were taken in September 1951. Work on this task assignment was initiated in January 1952 and is continuing.

The object of this project is to develop cameras suitable for obtaining good quality photographs of missiles in flight, using normal daylight for illumination and using object distances consistent with safety and convenience.



## DETAILS OF THE DEVELOPMENT PROGRAM

### Description of the Program

The program is being conducted in the following phases:

a. Phase A - Improvements in the improvised 35mm camera to permit immediate utilization in current ordnance development and test programs.

b. Phase B - Development of a drum-type Ballistic Synchro-Camera of moderate film speed.

c. Phase C - Design and construction of a high-speed drum type camera.

Phase A of this program has been completed and is the subject of this report.

### Principle of Operation of the Ballistic Synchro-Camera

The velocity of an image of a missile in flight is matched continuously with the velocity of a photographic film moving behind a narrow stationary slit which is perpendicular to the direction of film motion. Synchronization of the two velocities eliminates translational movement between the image and the film, and, if no other motion is present, a point on the image remains at the same point on the film during traverse of the slit.

Depending upon the width of the slit and the magnification of the lens employed, a virtual image of the slit of proportionate size will be located in the object space at the distance for which the lens is focused. As the object passes through this virtual slit, light reflected from a narrow portion of the object contained in the virtual slit will pass through the real slit onto the film. The total recorded image, therefore, is a time function, since the picture of the base of the object is taken at the same place as the picture of the nose, but at a later time. This time characteristic produces interesting effects in the recorded images. The principle of operation is graphically illustrated in Figure 1, Appendix (A).

DESCRIPTION OF THE PHASE A BALLISTIC SYNCHRO-CAMERAGeneral Features

The Phase A Camera is a 35mm continuously-moving film camera providing film transport at speeds adjustable from approximately 300 to 1,000 inches per second. This camera is basically a General Radio Type 651-AG Oscillograph Recorder with modifications in the film supply and take-up mechanism, lens mount, time-indexing system and film window. To meet operational requirements, provisions were made for mounting a reflecting prism on the lens mount to permit making side views of the trajectory without having to place the camera on its side. The camera is mounted on a base plate which can be inclined to bring the direction of film motion parallel to the missile trajectory.

Film Transport Mechanism

The film unwinds from the supply magazine in the upper part of the camera, passes over a free-running sprocket drum connected to an electric governor, and is wound on the motor driven take-up spool in the lower part of the camera. The speed of the film is regulated by selection of the applied voltages, and by adjustment of the electric governor. Constant speed is attained in approximately 0.5 seconds after starting. The camera runs at proper recording speed for about 3 seconds at a rate of 300 inches per second, and for about one second at 1,000 inches per second.

The spindles of the original supply and take-up magazines did not permit use of standard spools of 35mm film and required rewinding of film on the camera spool before use. These spindles were replaced by modified spindles which accommodate standard spools of 35mm film in 100-foot lengths and permit daylight loading.

### Lens Mount

Field requirements indicated the need for lenses of several focal lengths to satisfy requirements for the desired magnification and for the precise focusing of the camera. The 2-inch focal length lens mount supplied with the General Radio Oscillograph Recorder had insufficient mechanical strength to support a longer focus lens and the reflecting prism frequently required in field work. In addition, focusing of the basic unit could be accomplished only by means of the viewing telescope in the rear of the camera. This telescope had too great a depth of field for accurate focusing of the longer lenses and was not accessible when the camera was lying on its back as was frequently required in field use.

In order to make the camera suitable for this application the following modifications were made. A calibrated lens mount was constructed, providing precise focusing for a 10-inch focal length lens over object distances from 15 to 65 feet, and strong enough to support the heavy prism. Other mounts, accommodating 2- and 4-inch lenses and employing the same basic design, are under construction. The lens mount and its reflecting prism are shown mounted on the camera in Figures 2 and 3, Appendix (A).

### Prism

The camera operates with more uniform speed and at higher film transport rates when the axes of rotation of the film drive mechanism are horizontal. As long as this requirement is satisfied, the camera can be operated at any angle of elevation without affecting its operation. When test conditions require locating the camera to the side of the trajectory, a 45-90 degree reflecting prism is used in front of the lens to project the camera field of view into the missile trajectory.

### The Camera Slit

The 18- x 22mm film window of the original camera was removed and replaced by a plate having a slit, one inch in length, perpendicular to the direction of film motion. To meet requirements of exposure and resolution under a variety of conditions, a number of plates, having slits of 0.01-, 0.05-, 0.10- and 0.25-inch width were made. The slit plates may be easily interchanged in the field. The slit is approximately 0.008 inches from the film. As the slit width and the distance between the slit and the film decreases, the tolerable mismatch between image and film speeds for a given resolution increases. An analysis of the effects of slit width and distance from the film, and the numerical aperture of the lens, on effective exposure and camera performance is given in Appendix (B). Effects of aperture, slit width, distance between slit and film, and film speed on image registration time are presented in Table 1, Appendix (C). The effect of slit width on tolerable mismatch in film and image speed for blur not exceeding 0.01 inches in length is shown in Table 2, Appendix (C).

### Timing System

The spark coil timing system of the original camera was removed and a neon glow lamp, type NE-51, and an optical system providing better time resolution were installed. With a suitable timing generator this lamp provides sharp timing dots of about 6 microseconds duration at one millisecond intervals along the edge of the film.

### Control Box

Camera power supplies and timing circuits and an adjustable delay circuit, for triggering the flash lamps providing auxiliary illumination, are incorporated into a single control unit, capable of operating two cameras. Each camera is provided with relay-controlled, 60-cycle regulated power, adjustable from zero to 270 volts. The power relays are operated at a carefully determined interval before the missile is fired. This interval is selected so

that the cameras attain the desired recording speed before the missile reaches the camera field of view. A third outlet is provided on the timing generator for other equipment. A schematic circuit diagram of the control box is shown in Figure 4, Appendix (A).

#### Multiple Image Camera

A modification of the Phase A camera was developed in response to a need for two or more closely-spaced pictures of the same projectile on the same record. Two first-surface mirrors are mounted in the lens barrel as shown in Figure 5, Appendix (A). These mirrors are parallel to the plane defined by the lens axis and the length of the slit. The prism used with this lens is long enough to cover the angular field of view of the camera. This optical arrangement gives a number of paths by which the light from several planes intersecting the trajectory can reach the film. Five images of a missile can be produced by this optical arrangement. The two most distant images travel in the same direction as the central image, while the two intermediate images travel in the opposite direction.

The number of images which can be recorded by a system of this type is determined by the lens field of view and the length and spacing of the first surface mirrors. When two images only are desired from such a system, light traps consisting of shadow baffles are used to restrict the light from entering the optical system from the unwanted regions.

The multiple-image 5-inch lens mount and prism employed are shown in Figure 6, Appendix (A).

#### Auxiliary Lighting

Artificial illumination under adverse ambient light conditions is furnished by batteries of photoflash bulbs of the long peak type. The bulbs are fired at a predetermined time by a sequence timer or by the delay circuit in the control box.



OPERATIONAL PROCEDUREPreliminary Preparation

The following advance information is required in order to plan a field set-up of the Ballistic-Synchro-Camera:

a. Missile Velocity at Point of Recording:

This information is used in calculating the film speed required. As indicated in Table 2, Appendix (C), a considerable mismatch between speeds of image and film is tolerable without serious deterioration in photographic resolution.

b. Expected Trajectory:

With missiles whose trajectories have large angular dispersions, a somewhat larger ratio of object-to-image size than would otherwise be necessary may have to be used in order to provide a wider field of view.

c. Size and Characteristics of Missile:

If the missile is large, or has parts which separate from the body of the missile, the lateral field must be great enough to insure coverage.

d. Expected Ambient Illumination:

Auxiliary illumination is employed when the ambient illumination is inadequate for proper photographic registration.

e. Type of Information Desired:

When spin measurements are to be made, several lines are painted in a fore-and-aft direction on the missile. The lines need not be continuous, nor need they be on a cylindrical portion of the missile. The only requirement is that the missile have a surface of revolution about its longitudinal axis and that the painted lines represent the intersection of this surface with planes passing through the longitudinal axis of the missile.

-----

If accurate yaw information is to be obtained it is important that the lines of sight of the two Ballistic Synchro-Cameras intersect on the trajectory at a 90-degree angle.

When information on shock waves is desired, a striped background is required. A board large enough to cover the field of the virtual slit in object space is painted with alternate black and white stripes and placed behind the expected trajectory, just outside of the depth of focus of the camera lens. This gives a slightly fuzzy field of high contrast. Strong illumination of the background is required when shockwaves are to be recorded.

#### Choice of Lens and Film Speed

To obtain the maximum photographic resolution possible, the optical system must be properly focused, the slit must be of correct size and the film speed must be accurately established. From knowledge of the missile size a preferred object-to-image size ratio,  $R$ , is calculated. While there is no restriction on the length of the missile which can be recorded, the width of the field of view transverse to the trajectory is dependent upon  $R$  and the width of the film. The recording speed is also directly dependent upon this ratio.

The recording width of 35mm film is one inch, hence a large  $R$  must be employed if the transverse field of view is to accommodate the width of a large missile and its sabot parts and allow for possible deviations in the missile trajectory. When the velocity of the projectile is not high,  $R$  is determined by field coverage requirements. If, however, this value of  $R$  would lead to a film speed greater than the upper limit of the camera,  $R$  must be increased until an acceptable film speed is obtained. The film speed is, of course, equal to the missile velocity divided by  $R$ .

Having established an acceptable object-to-image size ratio, the distance between the camera and the trajectory is calculated by means of the following formula:

$$(R + 1)f = p$$

Where  $f$  = focal length of camera lens

$p$  = object distance (distance between camera lens and trajectory).

From considerations of terrain, amount of blast expected and other test conditions, a lens is chosen whose focal length permits selection of a suitable position for the camera.

To facilitate choice of the object-to-image ratio, film speed and object distance for a range of missile velocities, when using a lens of given focal length, graphs as shown in Figure 7, Appendix (A), have been prepared.

#### Adjustment of Film Speed

The film speed of the camera is determined by the supply voltage and the adjustment of the governor furnished as a part of the basic camera. By use of a variac and a constant voltage regulator in the camera power supply, the supply voltage can be adjusted and held to desired values. Efforts to calibrate the governor in terms of film speed at a given voltage have shown that successive identical settings of the governor will not produce the same film speeds. However, reproducibility of film speeds from run to run is satisfactory if the setting of the governor is not disturbed and the same supply voltage is used. In order to obtain a combination of supply voltage and governor setting that will produce the film speed desired for a test, the following procedure is used.

First, the camera is run without film but with a rubber belt between the motor driven take-up reel and sprocket wheel on the governor shaft. The supply voltage and governor are adjusted until the desired speed, as observed with a strobotac, is obtained. A 100-foot spool of film is then



run through the camera with the 1,000-cycle timing signal impressed. A section of the film, taken from the latter part of the run, is developed and an accurate measurement of the film speed is made using the timing marks. Corrections are then made to the voltage and governor settings and the process is repeated until a film speed approximately equivalent to the desired one is attained. In general it is easier to use this approximate film speed and adjust the object distance to fit this speed rather than to attempt a more precise film speed adjustment to fit a pre-selected object-to-image ratio. In practice, the film speed at which the camera was last used is recorded and the camera is operated at this speed, if feasible, on the next test.

#### Placement of Camera

For under-trajectory photography, the camera is located in the plane of the trajectory and tilted upon its back so that the optical axis of the camera is perpendicular to the trajectory. The camera is shown on its base plate, adjusted for under-trajectory photography at an angle-of-fire of zero degrees, in Figure 8, Appendix (A).

When photographing from one side of the trajectory, the camera is located at the calculated object distance and tilted so that the direction of film motion at the camera slit is parallel with the missile trajectory. A target, simulating the missile, located at the desired point in the trajectory, is then boresighted through the gun and the camera view is aligned on this target by tilting the reflecting prism on the front of the lens mount.

#### Processing of Film Records

Standard film processing techniques are followed. A fine grain developer providing high contrast is used. To obtain maximum film density and contrast on under-exposed film, the development period is sometimes extended almost to the point of producing chemical fog. This procedure was frequently necessary during the initial part of this investigation, but later adoption of wider camera slits closer to the film and the use of auxiliary lighting during cloudy days has improved the exposure conditions so that the need for over development has been reduced.

### RESULTS AND DISCUSSION

Typical examples of photographs obtainable with the Phase A cameras are shown in Figures 9 through 13, Appendix (A). These are enlargements from 35mm negatives. Velocities of the missiles appearing in these pictures ranged from 1,700 to 4,200 fps. These photographs are comparable in appearance to microflash pictures, but the latter could not have been obtained under the conditions of the tests.

Figure 14, Appendix (A), was obtained with the multiple-image camera. The right-hand picture was taken when the rocket was passing through the first virtual slit as the rocket was approaching the camera. The left-hand picture was recorded when the rocket passed through the second virtual slit as the rocket was receding from the camera. The latter view also shows smoke from the rocket which had arrived at the first virtual slit while the rocket was passing through the second virtual slit.

Shockwaves in the air surrounding the missile are shown in Figures 15 and 16, Appendix (A). The greater density of the air in the regions of compression in the shockwaves increases the refractive index, thus bending the light reflected from the striped background. Calculations show that these waves are analogous to those appearing in spark or in schlieren photographs. These shockwave traces are subject to the same distortions as the rest of the picture. If mismatch between optical image and film speeds is the only serious defect present, the apparent angle of the shockwaves can be corrected to true angle by determining the true relations between the time axis and the lateral space axis as indicated from recorded image length-width ratios compared to actual object length-width ratios. If the film speed is lower than the optical image speed, the apparent angle of the shockwaves will be increased.

Velocity, yaw and spin of a missile can be obtained from simple calculations based on measurements of a single photographic image of the missile. Yaw in a plane perpendicular to the line of sight is measured directly from the photographic image, subject to corrections resulting from

mismatch in optical image and film speeds. Methods of calculating velocity, yaw and spin from measurements on the photographic image are presented in Appendix (D). Photographs of a yawing and a spinning missile are shown in Figures 17 and 18, Appendix (A).

There were several opportunities for direct comparison of velocity determinations made from Ballistic Synchron-Camera photographs with velocity measurements obtained by conventional velocity measuring instrumentation. Analysis of the data indicated that the velocities obtained by this method have a probable error of about 1/2 percent if the missile is not yawing more than 5 degrees.

Accuracy of spin determination under good conditions is estimated to be 3 percent to 5 percent for a projectile fired from a 1 in 25 twist gun. There have not been enough yaw determinations made to establish a statistical confidence in the results, but the data obtained so far indicate an accuracy of the order of 2 degrees.

#### Distortions in the Photographic Images

Spin has the effect of causing longitudinal lines on the missile to have a sloping appearance as shown in Figure 18, Appendix (A). In Ballistic Synchron-Camera pictures of normally spinning projectiles the rifling marks, which at full spin are sloped at the angle of twist of the rifling, appear to be nearly parallel to the longitudinal axis of the missile.

Where there is a mismatch in the speeds of optical image and film, the recorded image will be lengthened or shortened in the direction of motion of the film by an amount proportional to the mismatch in speeds. If the discrepancy in speeds is within the tolerances indicated in Table 2, Appendix (C), the picture will still be sharp. This type of distortion is shown in Figure 19, Appendix (C), which is a composite of pictures of the same projectile taken by three Ballistic Synchron-Cameras located at different points along the projectile trajectory.



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If a sabot or other portion of a missile is spinning rapidly with a component of rotation about an axis parallel to the line of sight of the camera, a straight line on such a part may appear as a curve. This effect is shown in two of the sabots appearing in Figure 20, Appendix (A).

When the camera or prism are initially misaligned, the projectile may pass through the virtual slit of the camera at other than a 90-degree angle and the photographic image will be distorted. An example of this type of distortion is shown in Figure 21, Appendix (A). A fragment which is diverging from the trajectory at a considerable angle will also show this effect. Since the shape of the fragment is irregular, the distortion is less striking.

Sometimes the missile disintegrates before reaching the plane covered by the camera, and a picture of the fragments, smoke and other debris will be obtained as shown in Figure 22, Appendix (A).

### CONCLUSIONS

The Phase A Ballistic Synchro-Camera is an instrument for obtaining photographs of high resolution under conditions which preclude the use of conventional microflash techniques. A single picture can be reduced to yield information on missile velocity, spin and yaw with an accuracy dependent upon the ratio of object-to-image size and the degree with which the speed of the optical image has been matched by the speed of the film. Accuracies attainable under optimum conditions are considered to be: velocity, 1/2 percent; spin, 3 to 6 percent for a projectile fired from a 1 in 25 twist gun; and yaw, 2 degrees.

The camera requires no darkroom and may be used with long focal length lenses under daylight conditions.

Synchronization of the camera recording period with passage of the missile is not critical since recording can take place at any time during an interval of one to three seconds duration. The length of the recording period enables the coverage of burst firing in rapid-fire programs

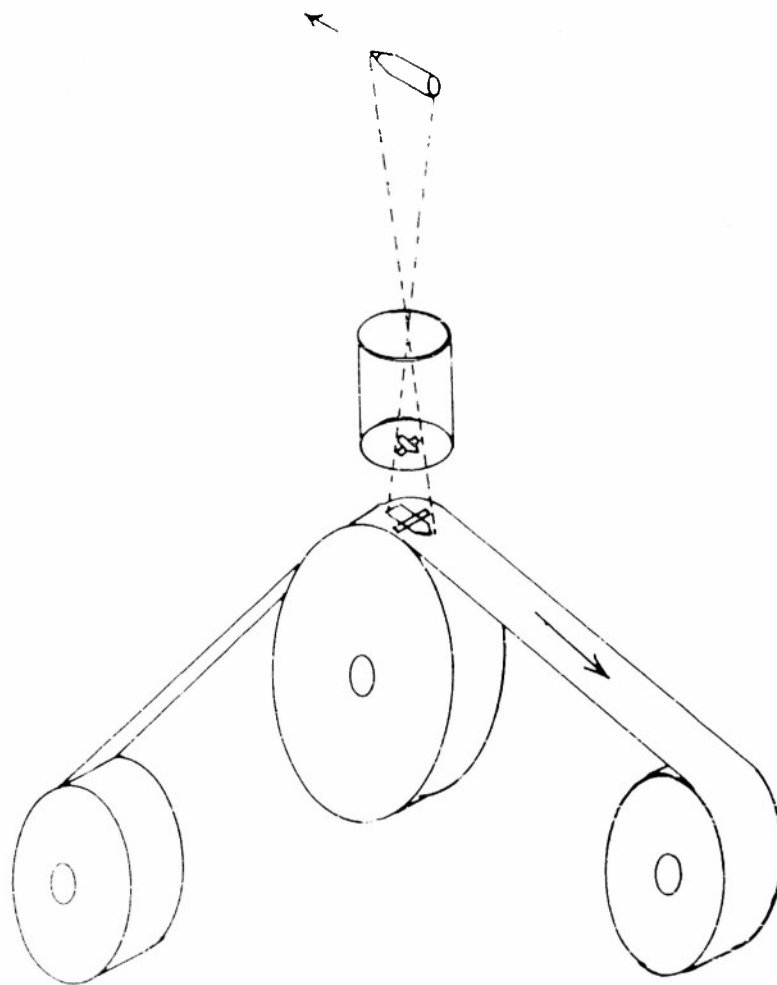
and the photography of long missiles and parts of missiles leading or trailing the main body of the missile. Though the velocity of a missile may vary considerably from that predicted, and though the missile may unexpectedly disintegrate, a picture will be obtained yielding useful information.

A serious limitation of the Phase A camera is the film speed. A speed of 1,000 inches per second is maximum for the camera and a speed of 2,000 inches per second is desirable. Such an increase in film speed would enable an increase in the size of the optical image which could be recorded, and this is especially desirable for small objects traveling at high velocity. For large objects, the width of the field provided by 35mm film imposes a restriction on the utilization of the camera, and a wider film is desirable.

#### REFERENCES

- (a) BUORD Conf ltr Re3d-WHP:bc NP9 Ser 32954  
of 23 Jan 1952
- (b) BUORD ltr Re3d-AHM:bc NP9 of 29 Jul. 1952
- (c) BUORD Conf ltr Re3d-CMD:bc NP9 of 28 Sep 1953
- (d) NAVPROV Conf ltr OB:CNJ:mrh Ll-2 Ser 12237  
of 1 Nov 1951

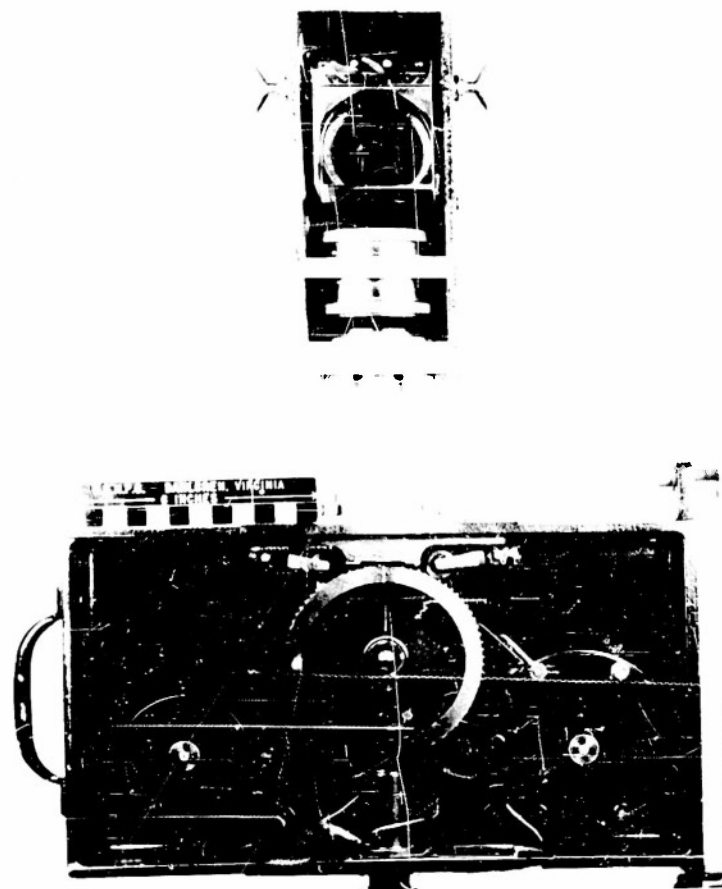
APPENDIX A



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Figure 1  
Operating Principle of the Ballistic Synchro-Camera.

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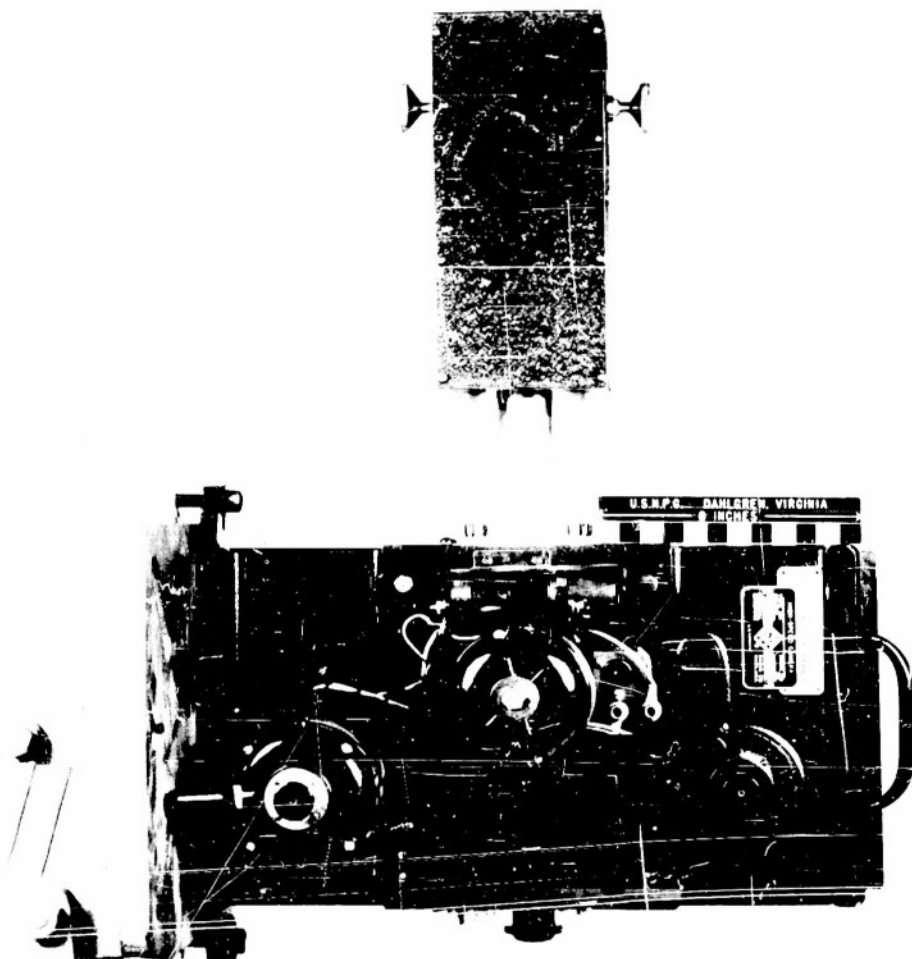
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Figure 2

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Side view of the 35mm Phase A Ballistic Synchro-Camera with cover plate removed. The use of standard 100-foot supply and take-up magazines facilitate loading operations in the field. The prism in front of the lens permits photography from the side of the trajectory and is removed for under-trajectory work.



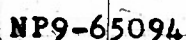


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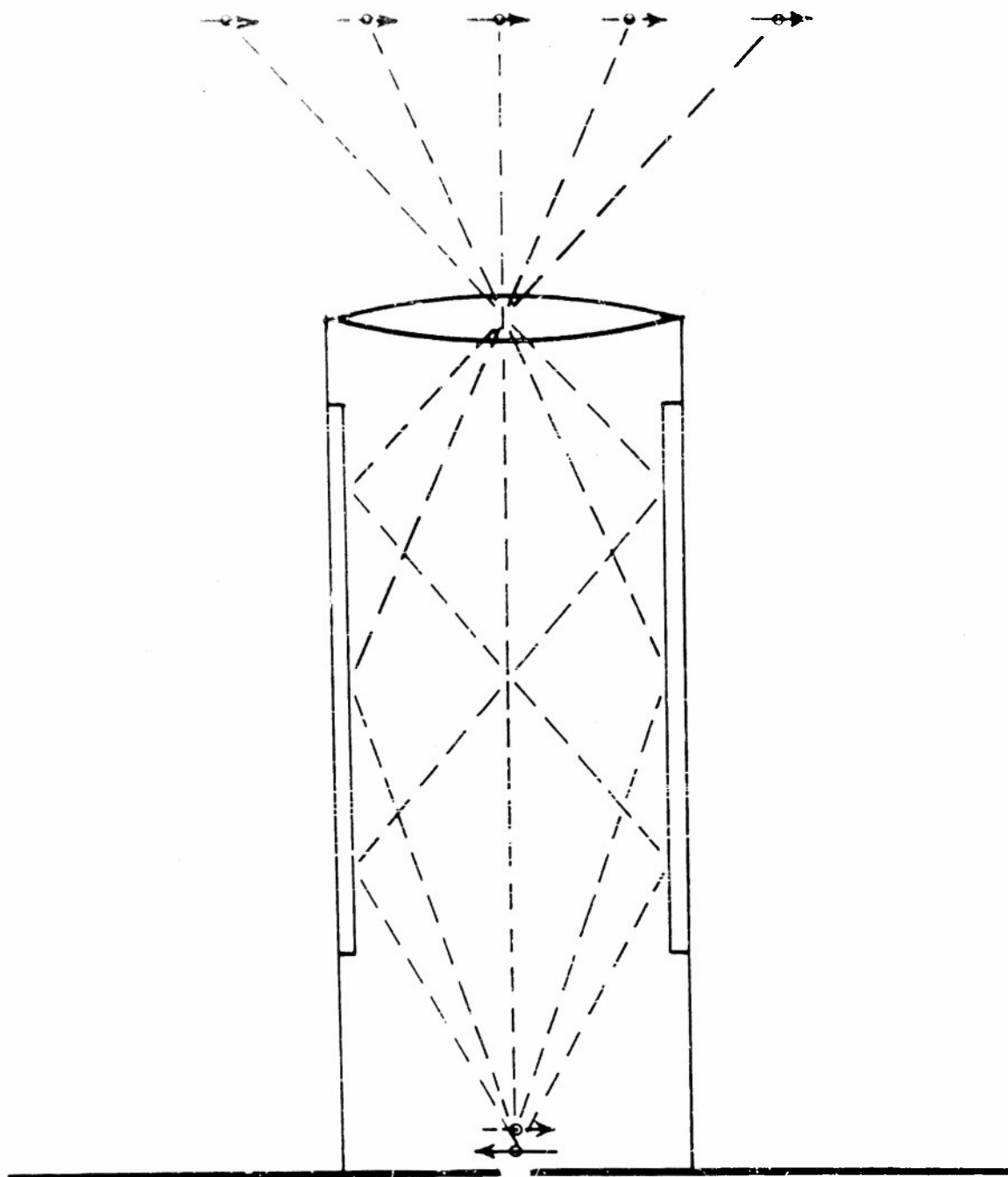
Figure 13

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The Phase A Ballistic Synchro-Camera in its normal operating position. On the left is the drive motor; in the center - the film speed governor; on the right - the friction brake for the supply magazine. The edge of the tilting base is shown at the far left.



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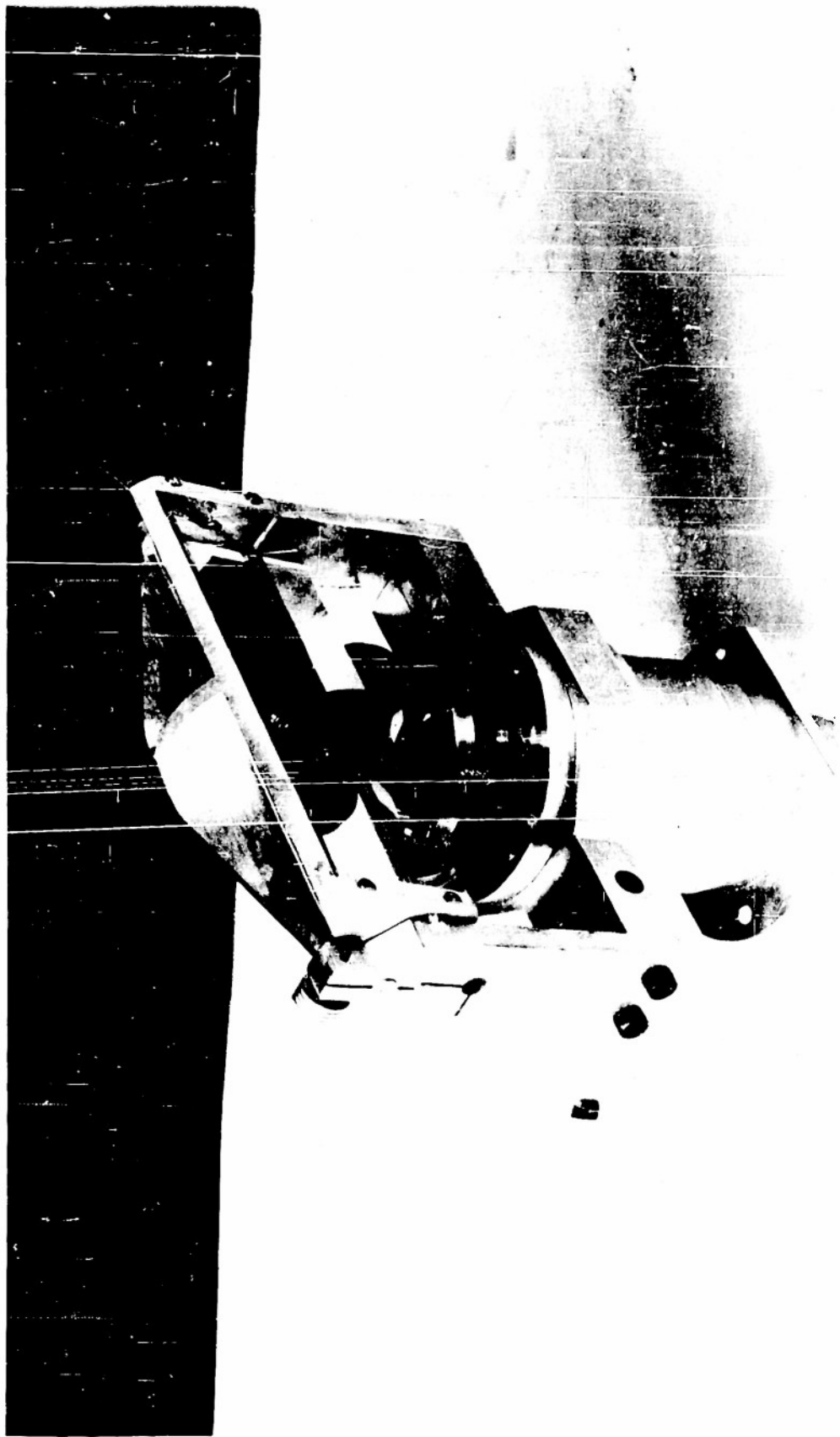


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Figure 5

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Manner of formation of optical images by the multiple-image lens.

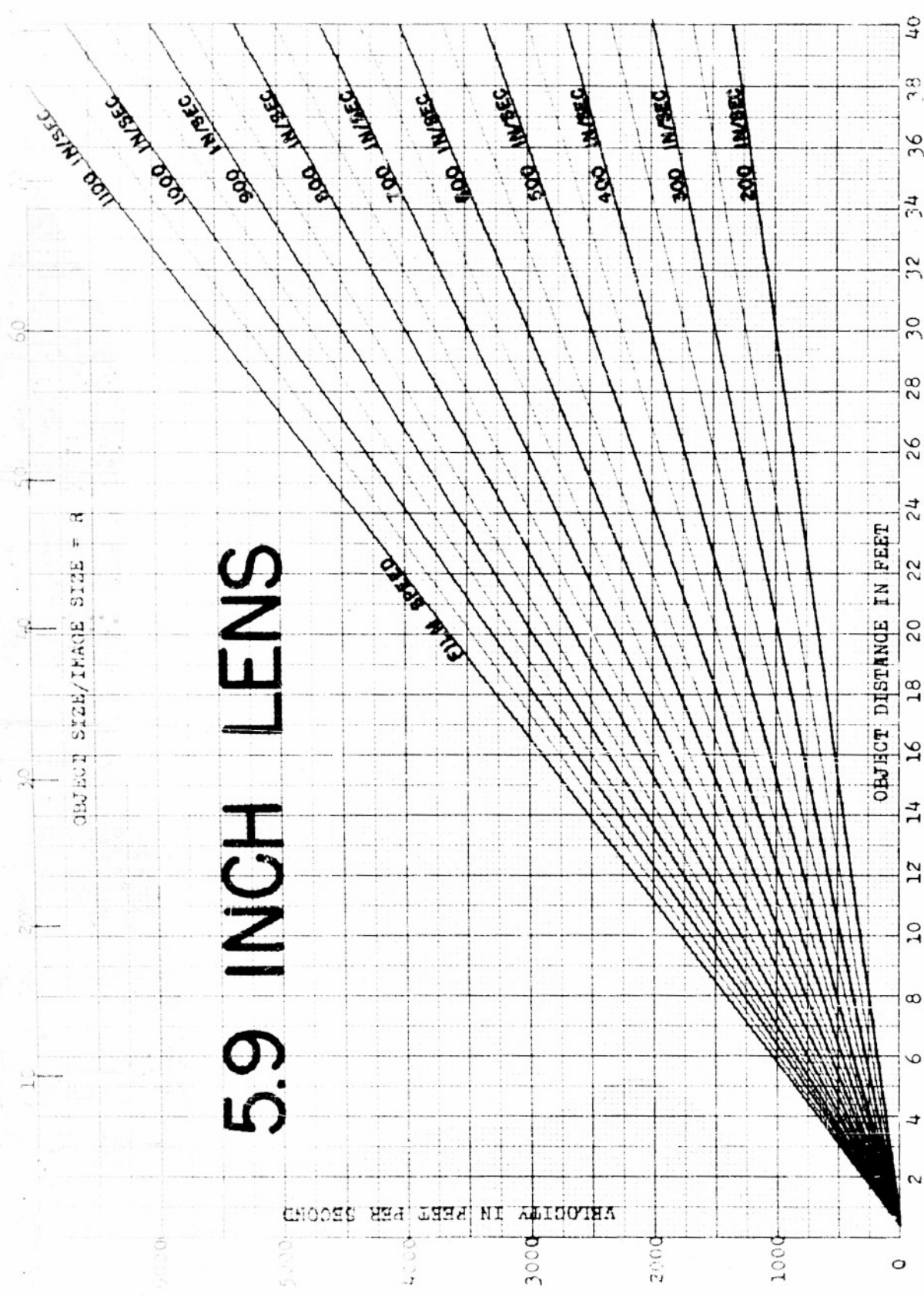


NP9-65096

The multiple-image, 5-inch,  $f/4$  lens for the Phase A Ballistic Synchron-Camera.  
The refracting prism is used when photographing from the side of the trajectory.

Figure 6

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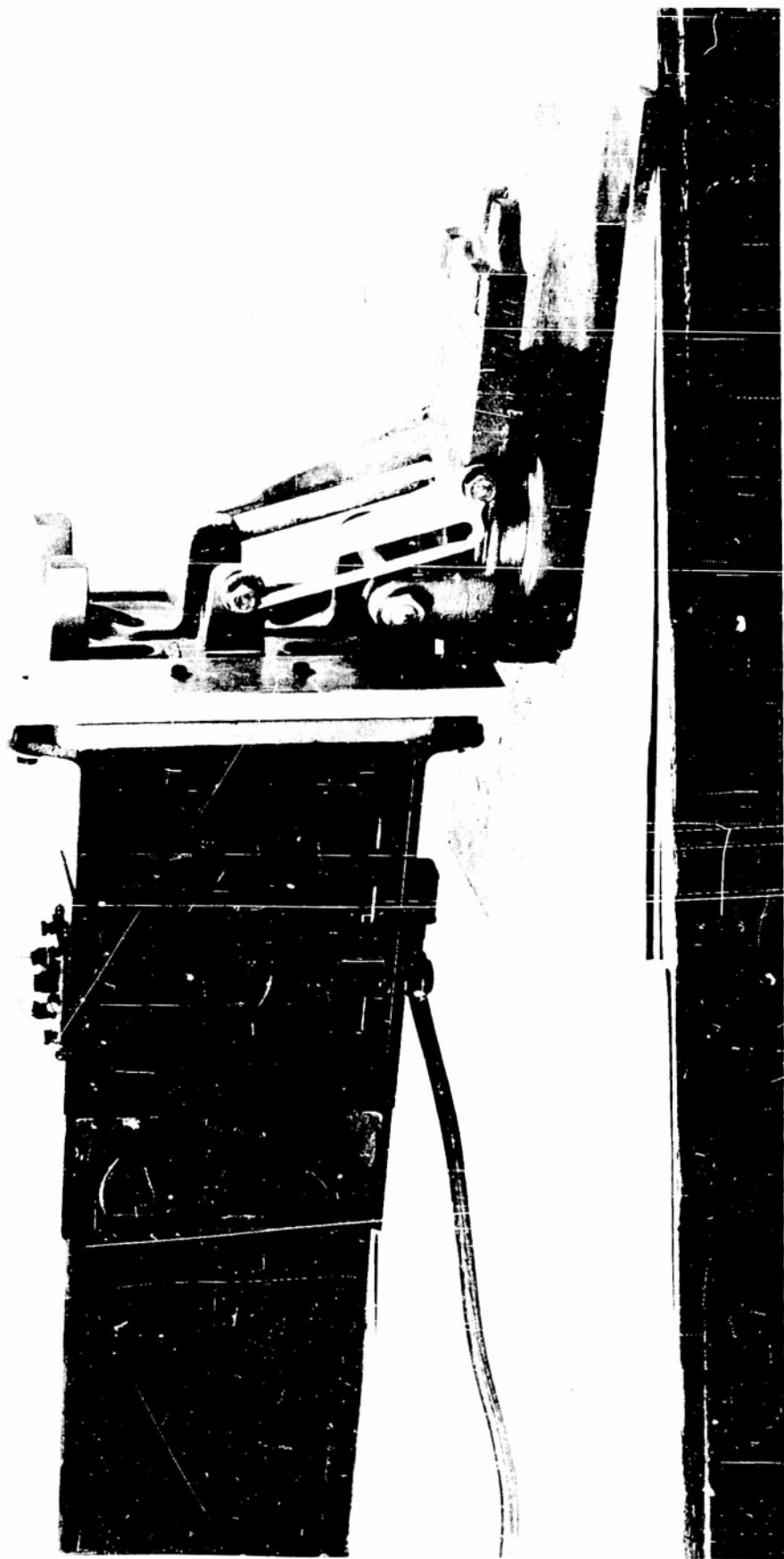


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Figure 7

A Ballistic Synchro chart for a 5.9-inch lens, used for computing film speed, object-to-image size ratio, and object distance for a given projectile velocity.

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Figure 8

Typical arrangement of the Phase A Ballistic Synchro-Camera for an under-trajectory view.

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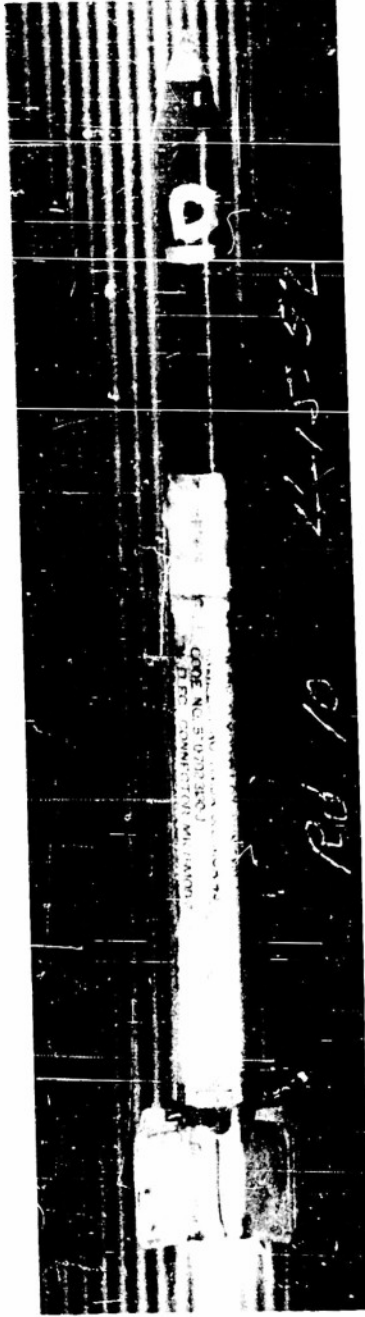


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Figure 9

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A fin-stabilized projectile in flight at a velocity of 3,700 fps. The camera was 32-feet from the trajectory and used a 5.9-inch lens with an  $f/3.5$  aperture. The slit width was 0.02 inches.



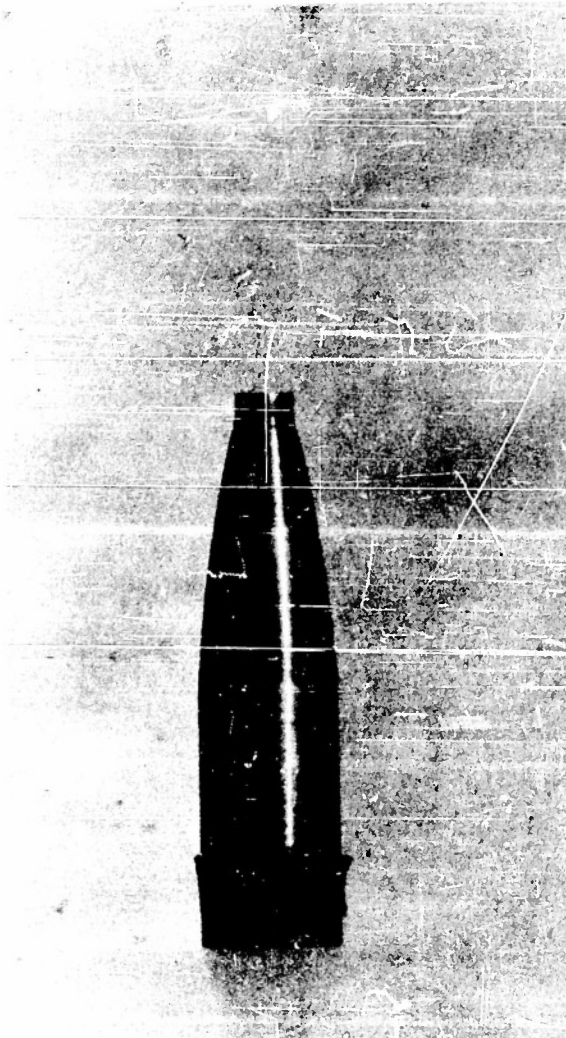
NP9-51711

Figure 10

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Printing on the body of this 5-inch rocket traveling at a velocity of 1,700 fps can be clearly read. This picture was taken from a location 20 feet to the side of the rocket trajectory. A 10-inch lens with an  $f/4.5$  aperture and a slit 0.05-inch wide were used.



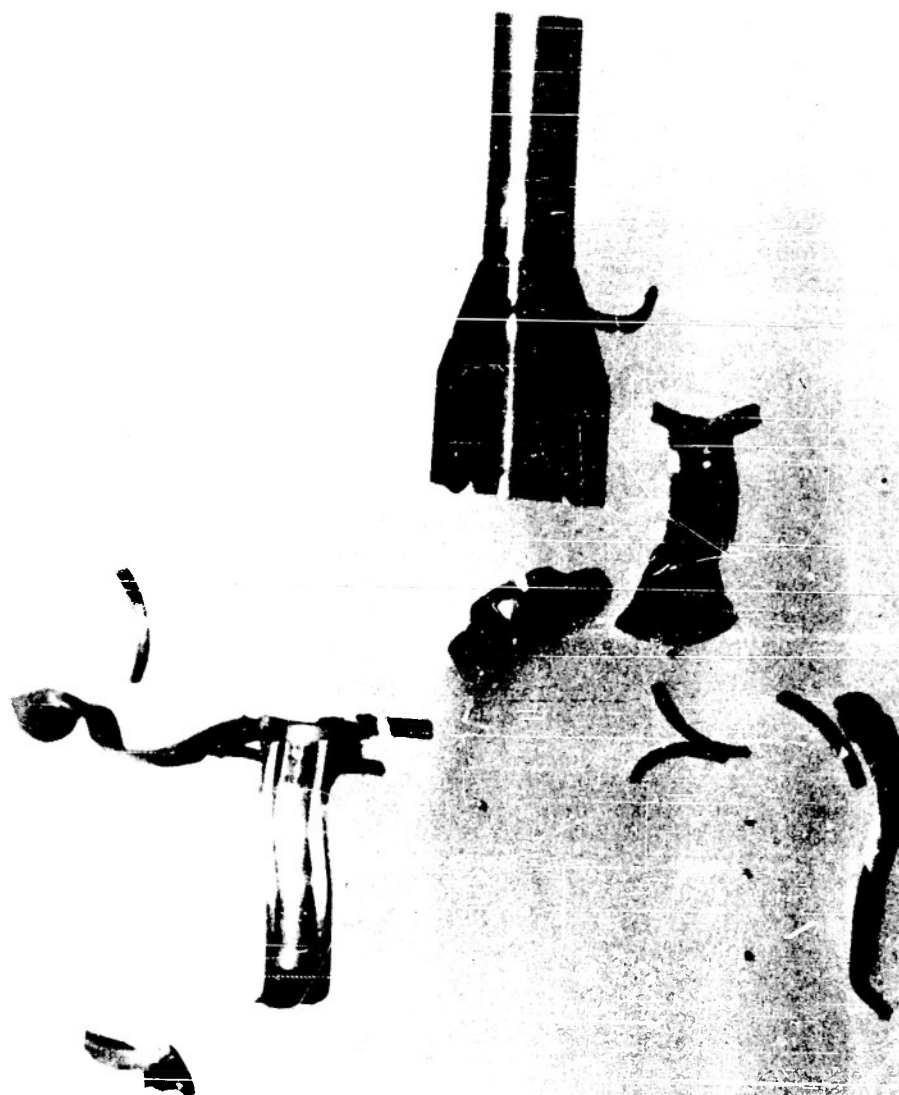


NP9-65279

This photograph shows poor banding as cause of a lot failure of 8-inch projectiles in flight test, despite attainment of full spin as indicated by registration of band engraving.

Figure 11

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NP9-46484

Figure 12

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Separation of sabots from a dummy arrow projectile in flight 64 feet from the gun muzzle. Velocity of the projectile was approximately 4,200 fps. The camera was located to the right of the trajectory. Note shock-wave formations around sabot parts.



NP9-65099

Figure 13

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Views of a fin-stabilized projectile in flight at 4,000 fps obtained by two cameras. The lower picture was obtained with ambient illumination only and was taken 3 milliseconds before the upper picture. A battery of flash bulbs supplied auxiliary illumination for the upper picture. Both cameras used 3.93-inch lenses with f/2.9 apertures and slits 0.05-inch in width.

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NP9-51710

Figure 14

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Two views of a rocket having 1,700 fps velocity obtained with the multiple-image 5-inch lens using an f/4 aperture and a slit 0.05 inches wide. Distance between corresponding points on the two rockets is approximately 11 feet (or 6-1/2 milliseconds).



NP9-51696

Figure 15

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Shock-wave formation around a missile having a velocity of 3,850 fps appears against the striped background. The picture was obtained with a 10-inch, f/4.5 lens and a slit 0.05-inch in width. The camera was located 42 feet to the side of the trajectory.



NP9-51709

Figure 16

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Shock-wave formation about a fin-stabilized projectile having a velocity of 4,000 fps. Note that shock-wave pattern shows only against the striped background. The picture was obtained with a 10-inch,  $f/4.5$  lens and a 0.05-inch wide slit. The camera position was 42 feet to the side of the projectile trajectory.



NP9-51697

Figure 17

A badly-yawing projectile having a velocity of about 3,100 fps. The fins of this projectile were burning. The picture was taken by a camera located 37 feet under the trajectory. A 10-inch,  $f/4.5$  lens and a 0.05-inch wide slit were used.

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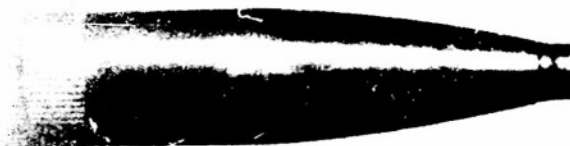


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Figure 18

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A spinning projectile showing how lines, which were painted on the projectile parallel to the longitudinal axis, appear at an angle to the axis on the photographic image.

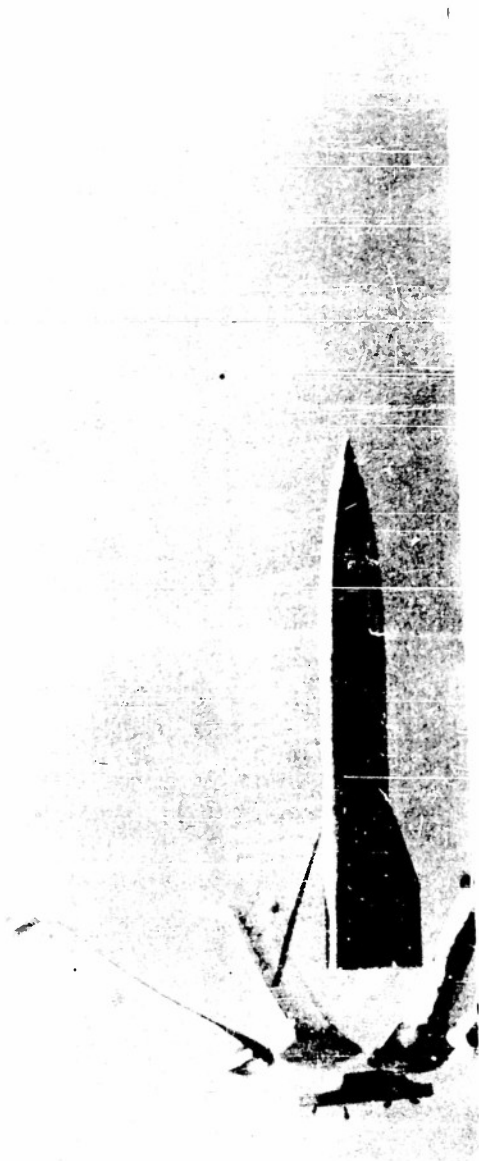


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Figure 19

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Illustration of distortion in length of image produced by mismatch between speeds of optical image and film. These pictures of the same 8-inch projectile were taken by three cameras having speeds arranged to cover the uncertainty in prediction of velocity.



NP9-51713

Figure 20

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Tumbling parts of the sabot of this projectile appear to be curved as a result of rotational velocity in the plane of the field. Note the four  $3/16$ -inch bolts following the base plate and the damaged fin separating from the projectile. The projectile velocity was 3,700 fps. The camera was located 23 feet from the trajectory and used a 5.9-inch,  $f/3.5$  lens and a 0.02-inch wide slit.



NP9-65102

Figure 21

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Distortions in the photographic image were caused by a camera misalignment so that the direction of film travel did not coincide with the direction of travel of the optical image of the missile. The velocity of the missile was 4,000 fps.



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Figure 22

A photograph of the fragments of a projectile which disintegrated in flight.

APPENDIX B

EFFECTS OF SLIT WIDTH AND DISTANCE FROM FILM ON EXPOSURE

Let us consider the manner in which the intensity of illumination of a point on the optical image varies as this point, together with the film, moves behind the slit. Figures 23A through 23D, Appendix (B), show conditions for large and small distances between slit and film. In these figures  $D$  is the diameter of the lens aperture,  $S$  is the width of the slit,  $X$  is the distance between slit and film and  $Q$  is the image distance between lens and film. The points  $L$ ,  $M$ ,  $N$  and  $O$  represent successive positions of the point on the image as it moves with the film. As the point moves from  $L$  to  $M$  luminous flux is incident upon it from an increasing area of the lens. From  $M$  to  $N$ , the point receives the maximum flux for a given lens aperture. From  $N$  to  $O$ , the flux decreases in a manner symmetrical with the increase that occurred between  $L$  and  $M$ .

It is clear that

$$\frac{LN}{Q} = \frac{S}{Q-X}$$

$$\frac{LM}{X} = \frac{D}{Q-X}$$

$$LM = NO$$

So that, introducing  $F$ , the numerical aperture of the lens, and setting the object at infinity so that  $F = Q/D$ , we have

$$LO = \frac{S + X/F}{1 - X/FD}$$

This is the total distance which the image point travels while the film is receiving any light from the object, and since the velocity of the film is constant,  $LO$  is proportional to the total exposure time.



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Since the image point receives light from any element of the lens only while the ray from that element to the image point is sweeping across the slit opening, a similar simple geometrical argument shows that the total luminous flux falling on a point of the film is proportional to

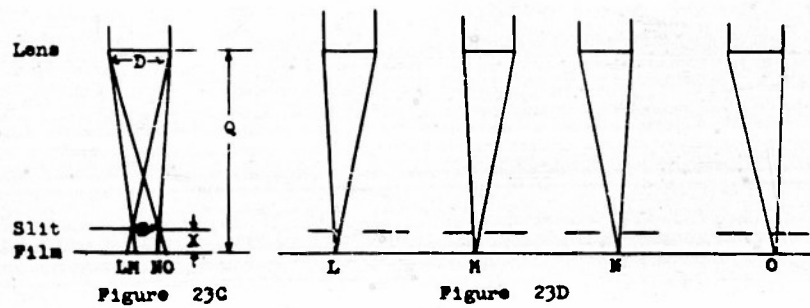
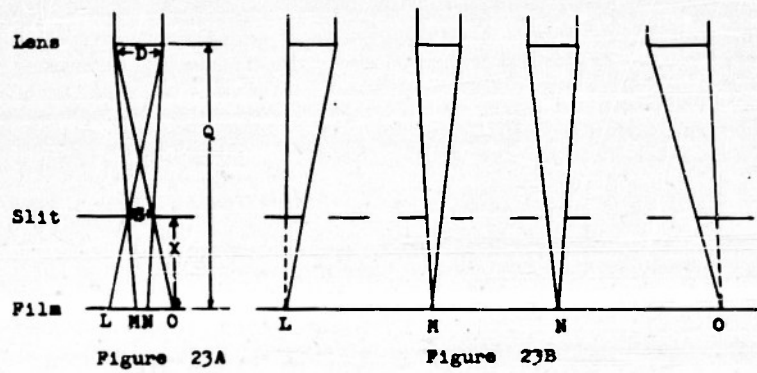
$$\frac{S}{1 - X/PD}$$

It is advantageous to keep the exposure time, or the distance the film moves during exposure, to as small a value as possible, so that mismatch of film velocity and missile velocity will produce as little blurring as possible. If this is done by reducing the slit width  $S$ , the density of the image will suffer. The only other way of reducing the exposure time is to reduce  $X$ ; that is, to place the slit as close to the film as practicable without interfering with the film motion.

In general there are practical limitations on the value of  $F$ . The usual procedure followed in selection of a lens is to determine the focal length required by the field test conditions and then to utilize the lens with the largest aperture available in this focal length. This selection then determines the minimum value of  $F$  and the slit width must then be made wide enough to produce an adequate exposure.

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APPENDIX B

APPENDIX C

**TABLE 1** **IMAGE REGISTRATION TIME**  
**FOR DIFFERENT SLIT-TO-FILM DISTANCES**

**A. Numerical Aperture -  $f/4.5$**   
**Slit-to-Film Distance - 0.120 inches**

<u>Film Speed</u> <u>Inches Per Second</u>	<u>.01 inches</u>	<u>.03 inches</u>	<u>.05 inches</u>
700	52.8 $\mu$ sec	81.4 $\mu$ sec	111.0 $\mu$ sec
800	46.2 $\mu$ sec	71.2 $\mu$ sec	96.2 $\mu$ sec
900	41.1 $\mu$ sec	63.3 $\mu$ sec	85.6 $\mu$ sec
1000	37.0 $\mu$ sec	57.0 $\mu$ sec	77.0 $\mu$ sec

**B. Numerical Aperture -  $f/1.9$**   
**Slit-to-Film Distance - 0.120 inches**

<u>Film Speed</u> <u>Inches Per Second</u>	<u>.01 inches</u>	<u>.03 inches</u>	<u>.05 inches</u>
700	104.3 $\mu$ sec	132.8 $\mu$ sec	161.4 $\mu$ sec
800	91.2 $\mu$ sec	116.2 $\mu$ sec	141.2 $\mu$ sec
900	81.1 $\mu$ sec	103.3 $\mu$ sec	125.6 $\mu$ sec
1000	73.0 $\mu$ sec	93.3 $\mu$ sec	113.0 $\mu$ sec

**C. Numerical Aperture -  $f/4.5$**   
**Slit-to-Film Distance - 0.008 inches**

<u>Film Speed</u> <u>Inches Per Second</u>	<u>.01 inches</u>	<u>.03 inches</u>	<u>.05 inches</u>
700	17.1 $\mu$ sec	45.7 $\mu$ sec	74.3 $\mu$ sec
800	15.0 $\mu$ sec	40.0 $\mu$ sec	68.0 $\mu$ sec
900	13.3 $\mu$ sec	35.5 $\mu$ sec	57.0 $\mu$ sec
1000	12.0 $\mu$ sec	32.0 $\mu$ sec	52.0 $\mu$ sec

**D. Numerical Aperture -  $f/1.9$**   
**Slit-to-Film Distance - 0.008 inches**

<u>Film Speed</u> <u>Inches Per Second</u>	<u>.01 inches</u>	<u>.03 inches</u>	<u>.05 inches</u>
700	20.0 $\mu$ sec	48.6 $\mu$ sec	77.1 $\mu$ sec
800	17.5 $\mu$ sec	42.5 $\mu$ sec	67.5 $\mu$ sec
900	15.6 $\mu$ sec	37.8 $\mu$ sec	60.0 $\mu$ sec
1000	14.0 $\mu$ sec	34.0 $\mu$ sec	54.0 $\mu$ sec

TABLE 2TOLERABLE MISMATCH BETWEEN OPTICAL IMAGE AND FILM SPEEDS  
FOR DIFFERENT SLIT-TO-FILM DISTANCES AND SLIT WIDTHS

The tolerance in speeds is based on perceptible blur at normal reading distance which is standardized as blur not greater than 0.01 inches. (If data are taken from the negative with the aid of a 5X instrument, or from a 5X print, the negative should have blur not greater than 0.002 inches.)

- A. Numerical Aperture -  $f/4.5$   
Slit-to-Film Distance - 0.120 inches

<u>Slit Widths</u>	<u>Registration Width on Film</u>	<u>Tolerable Mismatch of Speeds</u>
0.01 inches	0.037 inches	5.4 percent
0.02 inches	0.047 inches	4.3 percent
0.03 inches	0.057 inches	3.5 percent
0.04 inches	0.067 inches	3.0 percent
0.05 inches	0.077 inches	2.6 percent

- B. Numerical Aperture -  $f/1.9$   
Slit-to-Film Distance - 0.120 inches

<u>Slit Widths</u>	<u>Registration Width on Film</u>	<u>Tolerable Mismatch of Speeds</u>
0.01 inches	0.073 inches	2.7 percent
0.02 inches	0.083 inches	2.4 percent
0.03 inches	0.093 inches	2.2 percent
0.04 inches	0.103 inches	1.9 percent
0.05 inches	0.113 inches	1.8 percent

TABLE 2 (Continued)

C. Numerical Aperture -  $f/4.5$   
Slit-to-Film Distance - 0.008 inches

<u>Slit Widths</u>	<u>Registration Width on Film</u>	<u>Tolerable Mismatch of Speeds</u>
0.01 inches	0.012 inches	16.7 percent
0.02 inches	0.022 inches	9.1 percent
0.03 inches	0.032 inches	6.2 percent
0.04 inches	0.042 inches	4.8 percent
0.05 inches	0.052 inches	3.8 percent

D. Numerical Aperture -  $f/1.9$   
Slit-to-Film Distance - 0.008 inches

<u>Slit Widths</u>	<u>Registration Width on Film</u>	<u>Tolerable Mismatch of Speeds</u>
0.01 inches	0.014 inches	14.3 percent
0.02 inches	0.024 inches	8.3 percent
0.03 inches	0.034 inches	5.9 percent
0.04 inches	0.044 inches	4.5 percent
0.05 inches	0.054 inches	3.7 percent



**APPENDIX D**



MEASUREMENT OF MISSILE VELOCITY, YAW AND SPINVelocity

The velocity,  $V$ , of a projectile or missile is calculated from the known length of the missile and measurements on the film to determine the film speed and the length of the recorded image. The following formula is used:

$$V = \frac{V_f L_o}{L_I}$$

where  $V_f$  = film speed

$L_o$  = length of the missile

$L_I$  = length of photographic image

A mismatch between the speed of the film and the speed of the optical image within tolerable range of blur indicated in Table 2, Appendix (C), will not affect the accuracy of the velocity calculation since the image size, when combined with the film speed, is a measure of time, regardless of speed mismatch. The projectile has traveled a distance equal to its length in the time that the film has moved the length of the recorded image.

For an average projectile, the length of the photographic image is of the order of 0.8 inches and can be measured within a probable error of  $\pm 0.004$  inches or  $\pm 0.5$  percent. The length of the projectile is known or can be measured with negligible error. The film speed can be determined with a probable error of  $\pm 0.1$  percent. The probable error of a measurement of the velocity by this method is therefore of the order of  $\pm 0.5$  percent, or about 15 fps for a missile having a velocity of 3,000 fps. Comparison of velocities obtained from Ballistic Synchron-camera records and velocities measured by conventional solenoids and electronic chronographs have shown agreement within  $\pm 12$  fps about 95 percent of the time for velocities of the order of 2,500 fps. Hence, the estimated probable error of 0.5 percent is felt to be a conservative figure.

### Yaw

Instantaneous yaw in a plane normal to the direction of the optical axis is measured by finding the angle between the longitudinal axis of the recorded image and the direction of film motion. This measurement cannot be made accurately unless the mismatch between optical image and film speeds is small, or unless the velocity of the missile is accurately known from other instrumentation. Distortion of the photographic image caused by yaw makes accurate measurement of mismatch between optical image speed and film speed impossible.

A film speed greater than the optical image speed results in a lengthened photographic image, producing an apparent angle of yaw which is smaller than the actual angle of yaw in the missile. An increase in apparent yaw occurs if the film speed is lower than the optical image speed. The photographic image is shortened by this effect.

The tangent of the true angle of yaw is the product of the tangent of the apparent angle of yaw and the ratio of the film speed employed to the precise film speed required for no distortion of optical image.

An optical comparator is used to measure the apparent angle of yaw from the film. Although the accuracy of the angular readings made with the comparator is within one minute of arc, it is estimated that the probable error of measurement of yaw by this means is of the order of 2 degrees under optimum conditions (i.e., there is no mismatch in the speed of film and optical image and the quality of the photographic image is good). Mismatch in speeds of optical image and film reduces the accuracy of measurement by amounts depending upon the accuracy with which corrections mentioned in the preceding paragraph can be applied.

### Spin

When measurements of spin are desired, lines are painted on the missile body in a fore-and-aft direction so that they represent intersections of a plane passing through the longitudinal axis. The surface on which these lines are painted need not be cylindrical. The only requirement is that the

body have two places, well separated axially, where the body is bounded by a surface of revolution about the longitudinal axis. Rotation of the projectile during its translational motion will cause an angular displacement in the position of the lines recorded at the fore and aft stations. By measuring the diameter of the image and the distance from one end of the diameter to its intersection with the line, the angular position of the line can be computed at each station. The difference between the angular positions at the two stations is the angle of rotation. Experience has shown that this angle of rotation can be measured to an accuracy of 1 degree to 2 degree depending on the size of image and how well defined the lines are after firing. The greater the axial distance between the two stations, the larger will be the angle of rotation measured for a given spin rate, and the smaller will be the relative error produced by the 1 degree to 2 degree uncertainty in measuring the angle of rotation.

Mismatch of film speed with image speed does not introduce error in the spin measurement since the linear separation of the two stations on the missile is computed from the known dimensions of the missile and their positions on the recorded image. This procedure, of course, is based on the assumption that the missile has not suffered an axial deformation in firing.

With projectiles, a distance of about two calibers can usually be obtained between stations on the image. A projectile fired from a 1 in 25 twist gun and having full spin would turn through an angle of 28.8 degrees while moving a distance of two calibers along its trajectory. Its spin could, therefore, be measured to an accuracy of 3 to 6 percent.

Although spin is measured as the angle of rotation corresponding to a displacement of the missile along its trajectory, it may be easily converted to an angular velocity by use of the timing reference on the film. Spin measurements in this form would be more useful in studies of spin-stabilized rockets.

**APPENDIX E**

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G. E. Merritt and B. R. Zillgitt, Ballistic  
Instrumentation Development and Services  
Department, U. S. Naval Proving Ground, Dahlgren,  
Virginia 30 April 1954

### ABSTRACT

The Ballistic Synchro-Camera is under development at the Naval Proving Ground in fulfillment of a need for high-resolution photography of experimental missiles whose behavior in flight prohibits the use of conventional micro-flash equipment. The development program is being conducted in three phases, the first of which has been completed and is the subject of this report.

The principle on which this camera works is that of matching continuously the velocity of the image of the missile with the velocity of a film moving behind a narrow stationary slit which is perpendicular to the direction of film travel. Synchronization of the two velocities eliminates the translational movement of the image with respect to the film. Thus, if no other motion is present, a point on the image remains at the same point on the film during traverse of the slit, resulting in a photographic image of high quality and definition.

A camera of this type is ideally suited to the study of large, rapidly moving objects with results comparable in quality to those obtained under more restricted conditions by other methods. The camera is used in daylight with no restriction of ambient light, can be located at safe distances from missile trajectories, and can thus be used in the study of missiles producing dangerous fragments. It is especially suited to the study of rockets and self-luminous missiles. It has been used in studies of discarding sabot missiles, experimental projectiles, rockets, penetration of targets by rockets and projectiles, and fuze action.

In addition to the production of photographs of high resolution, valuable information on missile velocity, yaw and spin can be deduced from the records.



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The Phase A Ballistic Synchro-Camera, which is the subject of this report, is a modified 35mm oscillograph recording camera providing continuous film transport at speeds from 300 to 1,000 inches per second. Interchangeable slits, one inch in length and with widths varying from 0.01 to 0.25 inches, are provided with the camera to meet the range of test conditions encountered in the field.

Three Phase A Ballistic Synchro-Camera systems have been developed and are in regular field use at the Naval Proving Ground. Each system consists of two 35mm cameras, adjustable camera mounts, a timing generator and a control box.

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